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## IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Ray W. WOOD et al.  
Title: METHODS OF ADMINISTERING LIQUID DROPLET AEROSOLS OF  
NANOPARTICULATE DRUGS  
Appl. No.: 09/577,489  
Filing Date: 05/25/2000  
Examiner: Qazi, Sabiha Naim  
Art Unit: 1616

REQUEST FOR CLARIFICATION

HAND CARRY  
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Commissioner for Patents  
PO Box 1450  
Alexandria, Virginia 22313-1450

Sir:

This is a Request for Clarification of the final Office Action dated March 21, 2003. Following receipt of the Office Action, Applicants' counsel contacted the Examiner numerous times in mid-June and July to discuss the Office Action. On July 18, 2003, the Examiner suggested that Applicants file a Request for Clarification to resolve the issues discussed below.

On December 2, 2002, Applicants filed a Response to the first Office Action of July 30, 2002. However, in the final Office Action of March 21, 2003, the Examiner did not address *any* of Applicants' arguments made in the December 2 Response (none of Applicants' arguments had been submitted in a prior Response). Rather, the Examiner merely stated that "[a]rguments were fully considered but are not found persuasive therefore; rejection is maintained for the same reasons set forth in our previous office action."

P. TUCK  
#19  
7/31/03

Because the Examiner did not address any of the arguments made in Applicants' December 2 Response, Applicants are unable to further the prosecution of this case by filing a response to the final Office Action. Accordingly, Applicants request that the Examiner: (1) withdraw the Office Action of March 21, 2003; and (2) issue a new Office Action in which she addresses the arguments previously made by Applicants and which were not addressed in the Office Action of March 21, which are summarized below.

**Rejection of Claim 28 Under 35 U.S.C. § 112, Second Paragraph**

- Claim 28 was rejected under 35 U.S.C. § 112, second paragraph, because: (1) the reference to liquid droplets of one size and particles of another size in claim 28 is allegedly unclear; (2) the origin of the term "crystalline agent" is allegedly unclear; and (3) the use of the terms "comprising" and "comprises" in claim 28 allegedly render the claim indefinite because such terms allegedly fail to exclude unrecited claim elements.
  - In response to the rejection, Applicants amended claim 28 to only recite "liquid droplets," thereby removing any uncertainty caused by also reciting the singular form of the phrase.
  - To more particularly point out the claimed invention, claim 28 was amended to recite "therapeutic agent" instead of the allegedly indefinite "crystalline agent."
  - In response to the rejection for reciting the term "comprising," Applicants argued that in both *Gottzein* and *Davis*, upon which the Examiner relied, the Board affirmed *prior art* rejections of claims employing the term "comprising," which did not exclude additional elements found in the prior art. In contrast, the claimed invention is not taught or suggested by the prior art.
  - While the Examiner entered Applicants' claim amendments, the rejection under § 112, second paragraph, was maintained. No explanation for the maintained rejection was provided by the Examiner.

**Rejection of Claim 28 Under 35 U.S.C. § 112, Second Paragraph**

- Claims 28 – 45 were rejected under 35 U.S.C. § 112, first paragraph, as allegedly lacking enablement on two grounds: (1) the claim limitation “liquid droplet” allegedly lacks support in the specification; and (2) the method steps in claim 28 are allegedly not disclosed.
  - Support in the as-filed specification for the phrase “liquid droplets” recited in claim 28 was identified by Applicants: *See, e.g.*, specification at page 3, line 18 (“liquid droplets”); page 1, line 18 (“aqueous droplets”); page 2, line 26 (“droplets of an aqueous dispersion of nanoparticles”).
  - Applicants also identified ample enabling support for the method of claim 28. *See* specification at page 1, lines 14 (“delivery of agents to the lung”) and 23 (“respiratory drug delivery”); page 24, lines 5 – 15 (example showing delivery of an agent to a rabbit).
  - While the Examiner maintained the rejection under § 112, first paragraph, no explanation for the maintained rejection in view of Applicants’ arguments was provided by the Examiner.

**Rejection of Claims Under 35 U.S.C. § 103(a)**

- Claims 28 – 45 were rejected under 35 U.S.C. § 103(a) as being allegedly unpatentable over U.S. Patent No. 5,747,001 to Wiedmann et al. (“Wiedmann”) and U.S. Pat. No. 5,145,684 to Liversidge et al. (“Liversidge”).
  - Applicants first noted that Wiedmann is not available as a prior art reference as the effective filing date of the present application (February 24, 1995) and the filing date of commonly-assigned Wiedmann are identical.
    - In a teleconference of July 18, 2003, with Applicants’ counsel, the Examiner stated that the present application is a continuation-in-part of the first priority document and, therefore, the claimed invention may not be

entitled to the priority date of February 24, 2003 (this issue was not raised in the Office Action).

- For the convenience of the Examiner, attached is a copy of U.S. Application No. 08/394,103, filed on February 24, 1995, from which the present application claims benefit of priority. Exemplary support for the claimed invention can be found at, for example, page 3, lines 16-21; and page 4, lines 3-11 and 15-27.
- Applicants also argued in response to this rejection that Liversidge does not teach or suggest aerosol compositions of nanoparticulate active agents or methods of administering the same. Therefore, because Wiedmann is not available as prior art and Liversidge does not teach or suggest the claimed invention, it would not have been obvious to one of ordinary skill in the art to arrive at the claimed invention given the cited references.
- In addition, Applicants argued that one of ordinary skill in the art at the time the claimed invention was made would not have been motivated to make an aerosol composition comprising the nanoparticulate active agent composition of Liversidge for the following reasons:
  - The delivery efficiency of poorly soluble active agents via aerosolization can be unpredictable and inefficient: (1) Cameron et al. teach that nebulization of the water-insoluble drug budesonide showed that minimal amounts of drug substance were aerosolized *in-vitro*; and (2) Tiano and Nikander et al. have shown that nebulization of drug particles in the range of one to six microns (1000 to 6000 nm) in diameter (which are contained within the aerosolized water droplets) is very inefficient for air-jet nebulizers and essentially impossible for ultrasonic nebulizers.

- The prior art teaches that aerosolization of a poorly soluble active agent combined with a surfactant (i.e., a surface modifier) is difficult or impossible. *See* Tiano.
- None of Applicants' arguments made in response to the rejection of claims under § 103 were addressed by the Examiner.

### **CONCLUSION**

Given that the Examiner failed to address Applicants' arguments provided in the December 2 Response, which are summarized above in bullet point format, Applicants courteously request that the Examiner: (1) withdraw the Office Action of March 21, 2003; and (2) issue a new Office Action in which she addresses the arguments previously made by Applicants and which were not addressed in the Office Action of March 21.

It is Applicants understanding that the Examiner will be responding to this Request for Clarification within 10 days. Applicants welcome the Examiner's efforts to further the prosecution of this case.

The Examiner is invited to contact the undersigned by telephone with any questions or comments regarding this Request.

Respectfully submitted,

Date July 21, 2003

By Michele M. Simkin

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If there are any fees due in connection with the filing of this Amendment, please charge the fees to our Deposit Account No. 19-0741. If a fee is required for an extension of time under 37 C.F.R. § 1.136 not accounted for above, such an extension is requested and the fee should also be charged to our Deposit Account.

## BOX TENT APPLICATION

DOCKET 72046JJH

Honorable Commissioner of Patents  
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Washington, D.C. 20231

Sir:

Transmitted herewith for filing is  
the patent application of:

Ray W. Wood, et al

For: AEROSOLS CONTAINING  
NANOPARTICLE DISPERSIONS

Enclosed are:

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- ☐ sheets of Formal drawings.
- ☐ An assignment of the invention to.
- ☐ A certified copy of a application.
- ☐ An associate power of attorney.
- ☒ A Letter Under Rule 53.
- ☒ Combined Declaration for Patent Application and Power of Attorney.

The filing fee has been calculated as shown below:

FOR:	NO. FILED	NO. EXTRA	OTHER THAN A SMALL ENTITY	
			RATE	FEE
BASIC FEE				\$ 730
TOTAL CLAIMS	9 - 20 =	0	X 22 =	\$ 0
INDEPENDENT CLAIMS	4 - 3 =	1	X 76 =	\$ 76
MULTIPLE DEPENDENT CLAIM PRESENTED			+ 240	\$ 0
			TOTAL	\$ 806

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**AEROSOLS CONTAINING NANOPARTICLE DISPERSIONS**  
**FIELD OF THE INVENTION**

The present invention is directed to the field of nanoparticles and particularly in an aerosol form.

**5 BACKGROUND OF THE INVENTION**

Delivery of therapeutic agent to the respiratory tract is important for both local and systemic treatment of disease. With the conventional techniques, delivery of agents to the lung is extremely  
10 inefficient. Attempts to develop respirable aqueous suspensions of poorly soluble compounds have been unsuccessful. Micronized therapeutic agents suspended in aqueous media are too large to be delivered by aerosolized aqueous droplets. With conventional  
15 processes, it is estimated that only about 10 to 20% of the agent reaches the lung. Specifically, there is loss to the device used to deliver the agent, loss to the mouth and throat and with exhalation. These losses lead to variability in therapeutic agent levels and  
20 poor therapeutic control. In addition, deposition of the agent to the mouth and throat can lead to systemic absorption and undesirable side effects.

The efficiency of respiratory drug delivery is largely determined by the particle size distribution.  
25 Large particles (greater than 10 $\mu$ m) are primarily deposited on the back of the throat. Greater than 60% of the particles with sizes between 1 and 10  $\mu$ m pass with the air stream into the upper bronchial region of the lung where most are deposited. With particles less  
30 than about 1  $\mu$ m, essentially all of the particles enter the lungs and pass into the peripheral alveolar region; however, about 70% are exhaled and therefore are lost.

In addition to deposition, the relative rate of absorption and rate of clearance of the therapeutic  
35 agent must be considered for determining the amount of therapeutic agent that reaches the site of action.

Since 99.99% of the available area is located in the peripheral alveoli, rapid absorption can be realized with delivery of the particles to the periphery. For clearance, there is also differences between the  
5 central and peripheral regions of the lung. The peripheral alveolar region does not have ciliated cells but relies on macrophage engulfment for particle clearance. This much slower process can significantly extend the time during which the particles reside in  
10 the lung thereby enhancing the therapeutic or diagnostic effect. In contrast, particles deposited in the upper respiratory tract are rapidly cleared by mucociliary escalator. That is, the particles are trapped in the mucous blanket coating the lung surface  
15 and are transported to the throat. Hence, this material is either swallowed or removed by coughing.

While it has long been known that smaller droplets of an aerosol reach deeper into the respiratory system (Current Concepts in the Pharmaceutical Sciences:  
20 Dosage and Bioavailability, J. Swarbrick Ed., Lea and Febiger, Philadelphia, PA, 1973, pp. 97-148) these have largely been of theoretical interest. Simply knowing that smaller droplets of aerosol can be delivered deeper into the respiratory system does not solve the problem  
25 of incorporating sufficient therapeutic agent into the aerosol to be efficient, particularly where the therapeutic agent is only slightly soluble in the liquid for the aerosol.

Nanoparticles, described in U.S. Patent No.  
30 5,145,684, are particles consisting of a poorly soluble therapeutic or diagnostic agent onto which are adsorbed a non-crosslinked surface modifier, and which have an average particle size of less than about 400 nanometers (nm). However, no mention is made of attempts to  
35 nebulize (aerosolize or atomize are equivalent terms for the purpose of this disclosure) these compositions

and it is not apparent that nebulizing these composition would provide useful aerosols or that there would be any advantage for doing so.

Beclomethazone dipropionate monohydrate is an  
5 antiinflammatory steroid that is commercially available  
in the form of a nasal spray. According to the  
Physicians' Desk Reference®, it is sparingly soluble  
and when given by nasal inhalation in the form of an  
aqueous or aerosolized suspension, the drug is  
10 deposited primarily in the nasal passages. A portion  
of the drug is swallowed. Thus, delivery of  
beclomethazone is prone to all of the problems known  
for aerosolized suspensions of slightly soluble drugs  
mentioned above.

15 **SUMMARY OF THE INVENTION**

In accordance with the present invention, there is  
provided an aerosol comprising droplets of an aqueous  
dispersion of nanoparticles, said nanoparticles  
comprising insoluble therapeutic or diagnostic agent  
20 particles having a surface modifier on the surface  
thereof.

In another aspect of the invention, there is  
provided a method for forming an aerosol of a  
nanoparticle dispersion, said nanoparticles comprising  
25 insoluble therapeutic or diagnostic agent particles  
having a surface modifier on the surface thereof, said  
method comprising the steps of:

- a) providing a suspension of said nanoparticles;
- b) nebulizing said suspension so as to form an aerosol.

30 In yet another aspect of the invention, there is  
provided a method of treating a mammal comprising the  
steps of:

- a) forming an aerosol of an aqueous dispersion of  
nanoparticles, said nanoparticles comprising insoluble  
35 therapeutic agent particles having a surface modifier  
on the surface thereof;

b) administering said aerosol to the respiratory system of said mammal.

In yet another embodiment, there is provided a method of diagnosing a mammal, said method comprising the steps of:

- a) forming an aerosol of an aqueous dispersion of nanoparticles, said nanoparticles comprising insoluble diagnostic imaging agent particles having a surface modifier on the surface thereof;
- b) administering said aerosol to the respiratory system of said mammal; and
- c) imaging said imaging agent in said respiratory system.

#### DETAILED DESCRIPTION OF THE INVENTION

The compositions of the invention are aerosols. Aerosols can be defined for the present purpose as colloidal systems consisting of very finely divided liquid droplets dispersed in and surrounded by a gas. The droplets in the aerosols typically have a size less than about 50 microns in diameter although droplets of a much smaller size are possible.

The aerosols of the present invention are particularly useful in the treatment of respiratory related illnesses such as asthma, emphysema, respiratory distress syndrome, chronic bronchitis, cystic fibrosis and acquired immune deficiency syndrome including AIDS related pneumonia.

The aerosols of the invention are made by nebulizing the nanoparticle containing solution using a variety of known nebulizing techniques. Perhaps the simplest of systems is the "two-phase" system which consists of a solution or a suspension of active ingredient, in the present case, a nanoparticle containing a therapeutic or diagnostic agent, in a liquid propellant. Both liquid and vapor phases are present in a pressurized container and when a valve on

the container is opened, liquid propellant containing the nanoparticle dispersion is released. Depending on the nature of the ingredients and the nature of the valve mechanism, a fine aerosol mist or aerosol wet spray is produced.

There are a variety of nebulisers that are available to produce the aerosols of the invention including small volume nebulizers. Compressor driven nebulizers incorporate jet technology and use compressed air to generate the aerosol. Commercially available devices are available from Healthdyne Technologies Inc; Invacare Inc.; Mountain Medical Equipment Inc.; Pari Respiratory Inc.; Mada Mediacal Inc.; Puritan-Bennet; Schuco Inc.; Omron Healthcare Inc.; DeVilbiss Health Care Inc; and Hospitak Inc.

Ultrasonic nebulizers deliver high medication output and are used by patients suffering from severe asthma, or other severe respiratory related illnesses.

The particles comprise a therapeutic or diagnostic agent. (Therapeutic agents are sometimes referred to as drugs or pharmaceuticals. The diagnostic agent referred to is typically a contrast agent such as an x-ray contrast agent but can also be other diagnostic materials.) The therapeutic or diagnostic agent exists as a discrete, crystalline phase. The crystalline phase differs from a non-crystalline or amorphous phase which results from precipitation techniques, such as described in EPO 275,796.

The invention can be practiced with a wide variety of therapeutic or diagnostic agents. The therapeutic or diagnostic agent preferably is present in an essentially pure form. The therapeutic or diagnostic agent must be poorly soluble and dispersible in at least one liquid medium. By "poorly soluble" it is meant that the therapeutic or diagnostic agent has a solubility in the liquid dispersion medium of less than

about 10 mg/mL, and preferably of less than about 1 mg/mL. A preferred liquid dispersion medium is water. However, the invention can be practiced with other liquid media in which a therapeutic or diagnostic agent is poorly soluble and dispersible including, for example, aqueous salt solutions, safflower oil and solvents such as ethanol, t-butanol, hexane and glycol. The pH of the aqueous dispersion media can be adjusted by techniques known in the art.

10        Suitable therapeutic or diagnostic agents can be selected from a variety of known classes of therapeutic or diagnostic agents including, for example, analgesics, anti-inflammatory agents, anthelmintics, anti-arrhythmic agents, antibiotics (including  
15        penicillins), anticoagulants, antidepressants, antidiabetic agents, antiepileptics, antihistamines, antihypertensive agents, antimuscarinic agents, antimycobacterial agents, antineoplastic agents, immunosuppressants, antithyroid agents, antiviral  
20        agents, anxiolytic sedatives (hypnotics and neuroleptics), astringents, beta-adrenoceptor blocking agents, blood products and substitutes, cardiac inotropic agents, contrast media, corticosteroids such as beclomethazone dipropionate, cough suppressants  
25        (expectorants and mucolytics), diagnostic agents, diagnostic imaging agents, diuretics, dopaminergics (antiparkinsonian agents), haemostatics, immuriological agents, lipid regulating agents, muscle relaxants, parasympathomimetics, parathyroid calcitonin  
30        and biphosphonates, prostaglandins, radio-pharmaceuticals, sex hormones (including steroids), anti-allergic agents, stimulants and anoretics, sympathomimetics, thyroid agents, vasodilators and xanthines. Preferred therapeutic or diagnostic agents  
35        include those intended for oral administration and intravenous administration. A description of these

classes of therapeutic agents and diagnostic agents and a listing of species within each class can be found in Martindale, *The Extra Pharmacopoeia*, Twenty-ninth Edition, The Pharmaceutical Press, London, 1989. The  
5 therapeutic or diagnostic agents are commercially available and/or can be prepared by techniques known in the art.

Preferred diagnostic agents include the x-ray imaging agent WIN-8883 (ethyl 3,5-diacetamido-2,4,6-  
10 triiodobenzoate) also known as the ethyl ester of diatrazoic acid (EEDA), WIN 67722, i.e., (6-ethoxy-6-oxohexyl-3,5-bis(acetamido)-2,4,6-triiodobenzoate; ethyl-2-(3,5-bis(acetamido)-2,4,6-  
15 triiodobenzoyloxy)butyrate (WIN 16318); ethyl diatrizoxyacetate (WIN 12901); ethyl 2-(3,5-bis(acetamido)-2,4,6-triiodobenzoyloxy)propionate (WIN 16923); N-ethyl 2-(3,5-bis(acetamido)-2,4,6-  
20 triiodobenzoyloxy acetamide (WIN 65312); isopropyl 2-(3,5-bis(acetamido)-2,4,6-triiodobenzoyloxy) acetamide (WIN 12855); diethyl 2-(3,5-bis(acetamido)-2,4,6-triiodobenzoyloxy malonate (WIN 67721); ethyl 2-(3,5-bis(acetamido)-2,4,6-triiodobenzoyloxy) phenylacetate (WIN 67585); propanedioic acid, [[3,5-bis(acetylamino)-2,4,5-triiodobenzoyl]oxy]-,bis(1-methyl)ester (WIN  
25 68165); and benzoic acid, 3,5-bis(acetylamino)-2,4,6-triido-, 4-(ethyl-3-ethoxy-2-butenate) ester (WIN 68209). Suitable diagnostic agents are also disclosed in U.S. Patent No. 5,260,478; U.S. Patent No. 5,264,610; U.S. Patent No. 5,322,679 and U.S. Patent  
30 No. 5,300,739.

Preferred contrast agents include those which are expected to disintegrate relatively rapidly under physiological conditions, thus minimizing any particle-associated inflammatory response. Disintegration may  
35 result from enzymatic hydrolysis, solubilization of carboxylic acids at physiological pH, or other

mechanisms. Thus, poorly soluble iodinated carboxylic acids such as iodipamide, diatrizoic acid, and metrizoic acid, along with hydrolytically labile iodinated species such as WIN 67721, WIN 12901, WIN 68165, and WIN 68209 or others may be preferred.

#### **Surface Modifiers**

Suitable surface modifiers can preferably be selected from known organic and inorganic pharmaceutical excipients. Such excipients include various polymers, low molecular weight oligomers, natural products and surfactants. Preferred surface modifiers include nonionic and ionic surfactants.

Representative examples of surface modifiers include gelatin, casein, lecithin (phosphatides), gum acacia, cholesterol, tragacanth, stearic acid, benzalkonium chloride, calcium stearate, glycerol monostearate, cetostearyl alcohol, cetomacrogol emulsifying wax, sorbitan esters, polyoxyethylene alkyl ethers, e.g., macrogol ethers such as cetomacrogol 1000, polyoxyethylene castor oil derivatives, polyoxyethylene sorbitan fatty acid esters, e.g., the commercially available Tweens™, polyethylene glycols, polyoxyethylene stearates, colloidal silicon dioxide, phosphates, sodium dodecylsulfate, carboxymethylcellulose calcium, carboxymethylcellulose sodium, methylcellulose, hydroxyethylcellulose, hydroxypropylcellulose, hydroxypropylmethylcellulose phthalate, noncrystalline cellulose, magnesium aluminum silicate, triethanolamine, polyvinyl alcohol, and polyvinylpyrrolidone (PVP). Most of these surface modifiers are known pharmaceutical excipients and are described in detail in the Handbook of Pharmaceutical Excipients, published jointly by the American Pharmaceutical Association and The Pharmaceutical Society of Great Britain, the Pharmaceutical Press, 1986.

Particularly preferred surface modifiers include polyvinylpyrrolidone, tyloxapol, poloxamers such as Pluronic™ F68 and F108, which are block copolymers of ethylene oxide and propylene oxide, and polyxamines  
5 such as Tetronic™ 908 (also known as Poloxamine™ 908), which is a tetrafunctional block copolymer derived from sequential addition of propylene oxide and ethylene oxide to ethylenediamine, available from BASF, dextran, lecithin, dialkylesters of sodium sulfosuccinic acid,  
10 such as Aerosol OT™, which is a dioctyl ester of sodium sulfosuccinic acid, available from American Cyanimid, Duponol™ P, which is a sodium lauryl sulfate, available from DuPont, Triton™ X-200, which is an alkyl aryl polyether sulfonate, available from  
15 Rohn and Haas, Tween™ 20 and Tween™ 80, which are polyoxyethylene sorbitan fatty acid esters, available from ICI Specialty Chemicals; Carbowax™ 3550 and 934, which are polyethylene glycols available from Union Carbide; Crodesta™ F-110, which is a mixture of  
20 sucrose stearate and sucrose distearate, available from Croda Inc., Crodesta™ SL-40, which is available from Croda, Inc., and SA90HCO, which is  $C_{18}H_{37}-CH_2(CON(CH_3)CH_2(CHOH)_4CH_2OH)_2$ . Surface modifiers which have been found to be particularly useful include  
25 Tetronic™ 908, the Tweens™, Pluronic™ F-68 and polyvinylpyrrolidone. Other useful surface modifiers include:

decanoyl-N-methylglucamide;  
n-decyl  $\beta$ -D-glucopyranoside;  
30 n-decyl  $\beta$ -D-maltopyranoside;  
n-dodecyl  $\beta$ -D-glucopyranoside;  
n-dodecyl  $\beta$ -D-maltoside;  
heptanoyl-N-methylglucamide;  
n-heptyl- $\beta$ -D-glucopyranoside;  
35 n-heptyl  $\beta$ -D-thiogluco-side; n-hexyl  $\beta$ -D-glucopyranoside;

nonanoyl-N-methylglucamide;  
n-nonyl  $\beta$ -D-glucopyranoside;  
octanoyl-N-methylglucamide;  
n-octyl- $\beta$ -D-glucopyranoside;

5 octyl  $\beta$ -D-thioglucofuranoside; and the like.

Another useful surface modifier is tyloxapol (a nonionic liquid polymer of the alkyl aryl polyether alcohol type; also known as superinone or triton). This surface modifier is commercially available and/or  
10 can be prepared by techniques known in the art.

Another preferred surface modifier is p-isononylphenoxypoly(glycidol) also known as Olin-10G<sup>TM</sup> or Surfactant 10-G, is commercially available as 10G<sup>TM</sup> from Olin Chemicals, Stamford, Connecticut.

#### 15 **Non-Ionic Surface Modifiers**

Preferred surface modifiers can be selected from known non-ionic surfactants, including the poloxamines such as Tetronic<sup>TM</sup> 908 (also known as Poloxamine<sup>TM</sup> 908), which is a tetrafunctional block copolymer derived from  
20 sequential addition of propylene oxide and ethylene oxide to ethylenediamine, available from BASF, or Tetronic<sup>TM</sup> 1508 (T-1508), or a polymer of the alkyl aryl polyether alcohol type, such as tyloxapol.

The surface modifiers are commercially available  
25 and/or can be prepared by techniques known in the art. Two or more surface modifiers can be used in combination.

#### **Tyloxapol**

Tyloxapol (4-(1,1,3,3-tetramethylbutyl)-phenol  
30 polymer with ethylene oxide and formaldehyde) is a preferred surface modifier and is a nonionic liquid polymer of the alkyl aryl polyether alcohol type. Tyloxapol, also known as "Superinone", is disclosed as useful as a nonionic surface active agent in a lung  
35 surfactant composition in U.S. Patent No. 4,826,821 and

as a stabilizing agent for 2-dimethylaminoethyl 4-n-butylaminobenzoate in U.S. Patent No. 3,272,700.

Tyloxapol may be associated with the nanoparticles and may function as a surface modifier, as a stabilizer, and/or as a dispersant. Alternatively, the tyloxapol may serve other purposes. Tyloxapol may serve all three functions. The tyloxapol may serve as a stabilizer and/or a dispersant, whereas another compound acts as a surface modifier.

#### 10 **Auxiliary Surface Modifiers**

Particularly preferred auxiliary surface modifiers are those which impart resistance to particle aggregation during sterilization and include dioctylsulfosuccinate (DOSS), polyethylene glycol, glycerol, sodium dodecyl sulfate, dodecyl trimethyl ammonium bromide and a charged phospholipid such as dimyristoyl phosphatidyl glycerol. The surface modifiers are commercially available and/or can be prepared by techniques known in the art. Two or more surface modifiers can be used in combination.

#### 20 **Block Copolymer Surface Modifiers**

One preferred surface modifier is a block copolymer linked to at least one anionic group. The polymers contain at least one, and preferably two, three, four or more anionic groups per molecule. Preferred anionic groups include sulfate, sulfonate, phosphonate, phosphate and carboxylate groups. The anionic groups are covalently attached to the nonionic block copolymer. The nonionic sulfated polymeric surfactant has a molecular weight of 1,000-50,000, preferably 2,000-40,000 and more preferably 3,000-30,000. In preferred embodiments, the polymer comprises at least about 50%, and more preferably, at least about 60% by weight of hydrophilic units, e.g., alkylene oxide units. The reason for this is that the

presence of a major weight proportion of hydrophilic units confers aqueous solubility to the polymer.

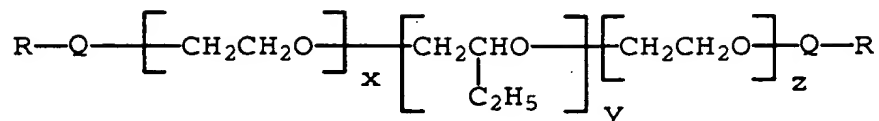
5 A preferred class of block copolymers useful as surface modifiers herein includes sulfated block copolymers of ethylene oxide and propylene oxide. These block copolymers in an unsulfated form are commercially available as Pluronic<sup>TM</sup>. Specific examples of the unsulfated block copolymers include F68, F108 and F127.

10 Another preferred class of block copolymers useful herein include tetrafunctional block copolymers derived from sequential addition of ethylene oxide and propylene oxide to ethylene diamine. These polymers, in an unsulfated form, are commercially available as  
15 Tetronics<sup>TM</sup>.

Another preferred class of surface modifiers contain at least one polyethylene oxide (PEO) block as the hydrophilic portion of the molecule and at least one polybutylene oxide (PBO) block as the hydrophobic  
20 portion. Particularly preferred surface modifiers of this class are diblock, triblock, and higher block copolymers of ethylene oxide and butylene oxide, such as are represented, for example, by the following structural formula:

25  $\text{-(PEO)- (PBO)-}$ ;  $\text{-(PEO)- (PBO)- (PEO)-}$ ; and  $\text{-(PEO)- (PBO)- (PEO)- (PBO)-}$ . The block copolymers useful herein are known compounds and/or can be readily prepared by techniques well known in the art.

Highly preferred surface modifiers include  
30 triblock copolymers of the structure  $\text{-(PEO)- (PBO)- (PEO)-}$  having molecular weights of 3800 and 5000 which are commercially available from Dow Chemical, Midland, Michigan, and are referred to as B20-3800 and B20-5000. These surface modifiers contain about 80% by weight  
35 PEO. In a preferred embodiment, the surface modifier is a triblock polymer having the structure:



Q is an anionic group

5 wherein R is H or a metal cation such as Na<sup>+</sup>, K<sup>+</sup> and the like, x is 15-700, y is 5-200 and z is 15-700.

#### Grinding

The described particles can be prepared in a method comprising the steps of dispersing a therapeutic  
10 or diagnostic agent in a liquid dispersion medium and applying mechanical means in the presence of grinding media to reduce the particle size of the therapeutic or diagnostic agent to an effective average particle size of less than about 400 nm. The particles can be  
15 reduced in size in the presence of a surface modifier. Alternatively, the particles can be contacted with a surface modifier after attrition.

The therapeutic or diagnostic agent selected is obtained commercially and/or prepared by techniques  
20 known in the art in a conventional coarse form. It is preferred, but not essential, that the particle size of the coarse therapeutic or diagnostic agent selected be less than about 100 μm as determined by sieve analysis. If the coarse particle size of the therapeutic or  
25 diagnostic agent is greater than about 100 μm, then it is preferred that the particles of the therapeutic or diagnostic agent be reduced in size to less than 100 μm using a conventional milling method such as airjet or fragmentation milling.

30 The coarse therapeutic or diagnostic agent selected can then be added to a liquid medium in which it is essentially insoluble to form a premix. The concentration of the therapeutic or diagnostic agent in the liquid medium can vary from about 0.1 - 60%, and

preferably is from 5 - 30% (w/w). It is preferred, but not essential, that the surface modifier be present in the premix. The concentration of the surface modifier can vary from about 0.1 to about 90%, and preferably is 1 - 75%, more preferably 20-60%, by weight based on the total combined weight of the therapeutic or diagnostic agent and surface modifier. The apparent viscosity of the premix suspension is preferably less than about 1000 centipoise

10 The premix can be used directly by subjecting it to mechanical means to reduce the average particle size in the dispersion to less than 400 nm. It is preferred that the premix be used directly when a ball mill is used for attrition. Alternatively, the therapeutic or  
15 diagnostic agent and, optionally, the surface modifier, can be dispersed in the liquid medium using suitable agitation, e.g., a roller mill or a Cowles type mixer, until a homogeneous dispersion is observed in which there are no large agglomerates visible to the naked  
20 eye. It is preferred that the premix be subjected to such a premilling dispersion step when a recirculating media mill is used for attrition.

The mechanical means applied to reduce the particle size of the therapeutic or diagnostic agent conveniently can take the form of a dispersion mill.  
25 Suitable dispersion mills include a ball mill, an attritor mill, a vibratory mill, and media mills such as a sand mill and a bead mill. A media mill is preferred due to the relatively shorter milling time  
30 required to provide the intended result, i.e., the desired reduction in particle size. For media milling, the apparent viscosity of the premix preferably is from about 100 to about 1000 centipoise. For ball milling, the apparent viscosity of the premix preferably is from  
35 about 1 up to about 100 centipoise. Such ranges tend

to afford an optimal balance between efficient particle fragmentation and media erosion.

#### **Preparation Conditions**

5       The attrition time can vary widely and depends  
primarily upon the particular mechanical means and  
processing conditions selected. For ball mills,  
processing times of up to five days or longer may be  
required. On the other hand, processing times of less  
10   than 1 day (residence times of one minute up to several  
hours) have provided the desired results using a high  
shear media mill.

      The particles must be reduced in size at a  
temperature which does not significantly degrade the  
therapeutic or diagnostic agent. Processing  
15   temperatures of less than about 30 - 40°C are  
ordinarily preferred. If desired, the processing  
equipment can be cooled with conventional cooling  
equipment. The method is conveniently carried out  
under conditions of ambient temperature and at  
20   processing pressures which are safe and effective for  
the milling process. For example, ambient processing  
pressures are typical of ball mills, attritor mills and  
vibratory mills. Control of the temperature, e.g., by  
jacketing or immersion of the milling chamber in ice  
25   water are contemplated. Processing pressures from  
about 1 psi (0.07 kg/cm<sup>2</sup>) up to about 50 psi (3.5  
kg/cm<sup>2</sup>) are contemplated. Processing pressures from  
about 10 psi (0.7 kg/cm<sup>2</sup>) to about 20 psi (1.4 kg/cm<sup>2</sup>)  
are typical.

30       The surface modifier, if it was not present in the  
premix, must be added to the dispersion after attrition  
in an amount as described for the premix above.  
Thereafter, the dispersion can be mixed, e.g., by  
shaking vigorously. Optionally, the dispersion can be  
35   subjected to a sonication step, e.g., using an  
ultrasonic power supply. For example, the dispersion

can be subjected to ultrasonic energy having a frequency of 20 - 80 kHz for a time of about 1 to 120 seconds.

After attrition is completed, the grinding media is separated from the milled particulate product (in either a dry or liquid dispersion form) using conventional separation techniques, such as by filtration, sieving through a mesh screen, and the like.

#### 10 **Grinding Media**

The grinding media for the particle size reduction step can be selected from rigid media preferably spherical or particulate in form having an average size less than about 3 mm and, more preferably, less than about 1 mm. Such media desirably can provide the particles with shorter processing times and impart less wear to the milling equipment. The selection of material for the grinding media is not believed to be critical. We have found that zirconium oxide, such as 95% ZrO<sub>2</sub> stabilized with magnesia, zirconium silicate, and glass grinding media provide particles having levels of contamination which are believed to be acceptable for the preparation of pharmaceutical compositions. However, other media, such as stainless steel, titania, alumina, and 95% ZrO<sub>2</sub> stabilized with yttrium, are expected to be useful. Preferred media have a density greater than about 3 g/cm<sup>3</sup>.

#### **Polymeric Grinding Media**

The grinding media can comprise particles, preferably substantially spherical in shape, e.g., beads, consisting essentially of polymeric resin. Alternatively, the grinding media can comprise particles comprising a core having a coating of the polymeric resin adhered thereon.

In general, polymeric resins suitable for use herein are chemically and physically inert,

substantially free of metals, solvent and monomers, and of sufficient hardness and friability to enable them to avoid being chipped or crushed during grinding.

Suitable polymeric resins include crosslinked

- 5 polystyrenes, such as polystyrene crosslinked with divinylbenzene, styrene copolymers, polycarbonates, polyacetals, such as Delrin™, vinyl chloride polymers and copolymers, polyurethanes, polyamides, poly(tetrafluoroethylenes), e.g., Teflon™, and other  
10 fluoropolymers, high density polyethylenes, polypropylenes, cellulose ethers and esters such as cellulose acetate, polyhydroxymethacrylate, polyhydroxyethyl acrylate, silicone containing polymers such as polysiloxanes and the like. The polymer can be  
15 biodegradable. Exemplary biodegradable polymers include poly(lactides), poly(glycolide) copolymers of lactides and glycolide, polyanhydrides, poly(hydroxyethyl methacrylate), poly(imino carbonates), poly(N-acylhydroxyproline)esters, poly(N-palmitoyl  
20 hydroxyproline) esters, ethylene-vinyl acetate copolymers, poly(orthoesters), poly(caprolactones), and poly(phosphazenes). In the case of biodegradable polymers, contamination from the media itself advantageously can metabolize in vivo into biologically  
25 acceptable products which can be eliminated from the body.

- The polymeric resin can have a density from 0.8 to 3.0 g/cm<sup>3</sup>. Higher density resins are preferred inasmuch as it is believed that these provide more  
30 efficient particle size reduction.

The media can range in size from about 0.1 to 3 mm. For fine grinding, the particles preferably are from 0.2 to 2 mm, more preferably, 0.25 to 1 mm in size.

- 35 In a particularly preferred method, a therapeutic or diagnostic agent is prepared in the form of

submicron particles by grinding the agent in the presence of a grinding media having a mean particle size of less than about 75 microns.

5       The core material of the grinding media preferably  
can be selected from materials known to be useful as  
grinding media when fabricated as spheres or particles.  
Suitable core materials include zirconium oxides (such  
as 95% zirconium oxide stabilized with magnesia or  
yttrium), zirconium silicate, glass, stainless steel,  
10    titania, alumina, ferrite and the like. Preferred core  
materials have a density greater than about 2.5 g/cm<sup>3</sup>.  
The selection of high density core materials is  
believed to facilitate efficient particle size  
reduction.

15       Useful thicknesses of the polymer coating on the  
core are believed to range from about 1 to about 500  
microns, although other thicknesses outside this range  
may be useful in some applications. The thickness of  
the polymer coating preferably is less than the  
20    diameter of the core.

      The cores can be coated with the polymeric resin  
by techniques known in the art. Suitable techniques  
include spray coating, fluidized bed coating, and melt  
coating. Adhesion promoting or tie layers can  
25    optionally be provided to improve the adhesion between  
the core material and the resin coating. The adhesion  
of the polymer coating to the core material can be  
enhanced by treating the core material to adhesion  
promoting procedures, such as roughening of the core  
30    surface, corona discharge treatment, and the like.

#### **Continuous Grinding**

      In a preferred grinding process, the particles are  
made continuously rather than in a batch mode. The  
continuous method comprises the steps of continuously  
35    introducing the therapeutic or diagnostic agent and  
rigid grinding media into a milling chamber, contacting

the agent with the grinding media while in the chamber to reduce the particle size of the agent, continuously removing the agent and the grinding media from the milling chamber, and thereafter separating the agent from the grinding media.

The therapeutic or diagnostic agent and the grinding media are continuously removed from the milling chamber. Thereafter, the grinding media is separated from the milled particulate agent (in either a dry or liquid dispersion form) using conventional separation techniques, in a secondary process such as by simple filtration, sieving through a mesh filter or screen, and the like. Other separation techniques such as centrifugation may also be employed.

In a preferred embodiment, the agent and grinding media are recirculated through the milling chamber. Examples of suitable means to effect such recirculation include conventional pumps such as peristaltic pumps, diaphragm pumps, piston pumps, centrifugal pumps and other positive displacement pumps which do not use sufficiently close tolerances to damage the grinding media. Peristaltic pumps are generally preferred.

Another variation of the continuous process includes the use of mixed media sizes. For example, larger media may be employed in a conventional manner where such media is restricted to the milling chamber. Smaller grinding media may be continuously recirculated through the system and permitted to pass through the agitated bed of larger grinding media. In this embodiment, the smaller media is preferably between about 1 and 300  $\mu$ m in mean particle size and the larger grinding media is between about 300 and 1000  $\mu$ m in mean particle size.

#### **Precipitation Method**

Another method of forming the desired nanoparticle dispersion is by microprecipitation. This is a method

of preparing stable dispersions of therapeutic and diagnostic agents in the presence of a surface modifying and colloid stability enhancing surface active agent free of trace of any toxic solvents or  
5 solubilized heavy metal impurities by the following procedural steps:

1. Dissolving the therapeutic or diagnostic agent in aqueous base with stirring,
- 10 2. Adding above #1 formulation with stirring to a surface active surfactant (or surface modifiers) solution to form a clear solution, and,
3. Neutralizing above formulation #2 with stirring with an appropriate acid solution. The procedure can be followed by:
- 15 4. Removal of formed salt by dialysis or diafiltration and
5. Concentration of dispersion by conventional means.

This microprecipitation process produces dispersion of therapeutic or diagnostic agents with Z-average particle diameter less than 400 nm (as measured  
20 by photon correlation spectroscopy) that are stable in particle size upon keeping under room temperature or refrigerated conditions. Such dispersions also demonstrate limited particle size growth upon  
25 autoclave-decontamination conditions used for standard blood-pool pharmaceutical agents.

Step 3 can be carried out in semicontinuous, continuous batch, or continuous methods at constant flow rates of the reacting components in computer-  
30 controlled reactors or in tubular reactors where reaction pH can be kept constant using pH-stat systems. Advantages of such modifications are that they provide

cheaper manufacturing procedures for large-scale production of nanoparticulate dispersion systems.

Additional surface modifier may be added to the dispersion after precipitation. Thereafter, the  
5 dispersion can be mixed, e.g., by shaking vigorously. Optionally, the dispersion can be subjected to a sonication step, e.g., using an ultrasonic power supply. For example, the dispersion can be subjected to ultrasonic energy having a frequency of 20-80 kHz  
10 for a time of about 1 to 120 seconds.

In a preferred embodiment, the above procedure is followed with step 4 which comprises removing the formed salts by diafiltration or dialysis. This is done in the case of dialysis by standard dialysis  
15 equipment and by diafiltration using standard diafiltration equipment known in the art. Preferably, the final step is concentration to a desired concentration of the agent dispersion. This is done either by diafiltration or evaporation using standard  
20 equipment known in this art.

An advantage of microprecipitation is that unlike milled dispersion, the final product is free of heavy metal contaminants arising from the milling media that must be removed due to their toxicity before product is  
25 formulated.

A further advantage of the microprecipitation method is that unlike solvent precipitation, the final product is free of any trace of trace solvents that may be toxic and must be removed by expensive treatments  
30 prior to final product formulation.

In another preferred embodiment of the microprecipitation process, a crystal growth modifier is used. A crystal growth modifier is defined as a compound that in the co-precipitation process

incorporates into the crystal structure of the microprecipitated crystals of the pharmaceutical agent, thereby hindering growth or enlargement of the microcrystalline precipitate, by the so called Ostwald ripening process. A crystal growth modifier (or a CGM) is a chemical that is at least 75% identical in chemical structure to the pharmaceutical agent. By "identical" is meant that the structures are identical atom for atom and their connectivity. Structural identity is characterized as having 75% of the chemical structure, on a molecular weight basis, identical to the therapeutic or diagnostic agent. The remaining 25% of the structure may be absent or replaced by different chemical structure in the CGM. The crystal growth modifier is dissolved in step #1 with the therapeutic or diagnostic agent.

#### **Particle Size**

As used herein, particle size refers to a number average particle size as measured by conventional particle size measuring techniques well known to those skilled in the art, such as sedimentation field flow fractionation, photon correlation spectroscopy, or disk centrifugation. When photon correlation spectroscopy (PCS) is used as the method of particle sizing the average particle diameter is the Z-average particle diameter known to those skilled in the art. By "an effective average particle size of less than about 400 nm" it is meant that at least 90% of the particles have a weight average particle size of less than about 400 nm when measured by the above-noted techniques. In preferred embodiments, the effective average particle size is less than about 300 nm and more preferably less than about 250 nm. In some embodiments, an effective average particle size of less than about 100 nm has been achieved. With reference to the effective

average particle size, it is preferred that at least 95% and, more preferably, at least 99% of the particles have a particle size less than the effective average, e.g., 400 nm. In particularly preferred embodiments, essentially all of the particles have a size less than 400 nm. In some embodiments, essentially all of the particles have a size less than 250 nm.

#### **Ratios**

The relative amount of therapeutic or diagnostic agent and surface modifier can vary widely and the optimal amount of the surface modifier can depend, for example, upon the particular therapeutic or diagnostic agent and surface modifier selected, the critical micelle concentration of the surface modifier if it forms micelles, the hydrophilic lipophilic balance (HLB) of the stabilizer, the melting point of the stabilizer, its water solubility, the surface tension of water solutions of the stabilizer, etc. The surface modifier preferably is present in an amount of about 0.1-10 mg per square meter surface area of the therapeutic or diagnostic agent. The surface modifier can be present in an amount of 0.1-90%, preferably 20-60% by weight based on the total weight of the dry particle.

#### **Diagnosis**

A method for diagnostic imaging for use in medical procedures in accordance with this invention comprises administering to the body of a test subject in need of a diagnostic image an effective contrast producing amount of the diagnostic image contrast composition. In addition to human patients, the test subject can include mammalian species such as rabbits, dogs, cats, monkeys, sheep, pigs, horses, bovine animals and the like. Thereafter, at least a portion of the body containing the administered contrast agent is exposed

to x-rays or a magnetic field to produce an x-ray or magnetic resonance image pattern corresponding to the presence of the contrast agent. The image pattern can then be visualized.

5        Any x-ray visualization technique, preferably, a high contrast technique such as computed tomography, can be applied in a conventional manner. Alternatively, the image pattern can be observed directly on an x-ray sensitive phosphor screen-silver  
10 halide photographic film combination or by use of a storage phosphor screen.

Visualization with a magnetic resonance imaging system can be accomplished with commercially available magnetic imaging systems such as a General Electric 1.5  
15 T Sigma imaging system [1H resonant frequency 63.9 megahertz (MHz)]. Commercially available magnetic resonance imaging systems are typically characterized by the magnetic field strength used, with a field strength of 2.0 Tesla as the current maximum and 0.2  
20 Tesla as the current minimum. For a given field strength, each detected nucleus has a characteristic frequency. For example, at a field strength of 1.0 Tesla, the resonance frequency for hydrogen is 42.57 MHz; for phosphorus-31 it is 17.24 MHz; and for sodium-  
25 23 it is 11.26 MHz.

A contrast effective amount of the diagnostic agent containing composition is that amount necessary to provide tissue visualization with, for example, magnetic resonance imaging or x-ray imaging. Means for  
30 determining a contrast effective amount in a particular subject will depend, as is well known in the art, on the nature of the magnetically reactive material used, the mass of the subject being imaged, the sensitivity of the magnetic resonance or x-ray imaging system and  
35 the like.

After administration of the compositions, the subject mammal is maintained for a time period sufficient for the administered compositions to be distributed throughout the subject and enter the  
5 tissues of the mammal. Typically, a sufficient time period is from about 20 minutes to about 90 minutes and, preferably from about 20 minutes to about 60 minutes.

The following examples are presented for a further  
10 understanding of the invention.

**Example 1 Using the Therapeutic agent Beclomethasone**  
Materials Beclomethasone dipropionate (BDP) and polyvinyl alcohol (PVA) were obtained from Sigma Chemical Co. (St. Louis, MO) and used as received. All  
15 other chemicals were analytical/reagent grade or better.

Nanoparticle preparation and characterization  
Nanoparticles were prepared by media milling a suspension of 5% beclomethasone dipropionate in an  
20 aqueous solutions of PVA. Thus, the PVA was the surface modifier. The resulting particle size distribution was determined by dynamic light scattering. The particle size distribution was periodically monitored throughout the course of the  
25 study.

Nebulization A gas cylinder of compressed air was used as the source, which was equipped with a pressure regulator. Oxygen connecting tubing joined from the regulator to the Puritan-Bennet Raindrop nebulizer  
30 (Lenexa, KA). One exit port of the T-connector of the nebulizer was blocked with a #2 rubber stopper. The other exit port was fitted with Tygon tubing (1/2" id). This in turn led initially to a calibrated flow meter from which the flow rate was set before each  
35 experiment. After calibration, the gas flow was

stopped by shutting off the main cylinder valve. The flow meter was removed, and the nebulizer was connected to a Y-tube with 24/40 joints by tubing (1/2" id, 6" length). The Y-tube was connected to the cascade  
5 impactor (Andersen Mark I, Andersen Samplers Ind. Atlanta, GA) by a constructed stainless steel adapter consisting of a tapered side that fit within the 24/40 ground glass joint and a cylindrical section with rubber o-ring gasket that fit into the top of the  
10 cascade impactor. The air flow rate through the impactor was drawn by a vacuum pump and regulated by a calibrated flow meter to the recommended 28.3 L/min.

Preliminary studies indicated that pressures between 20 and 40 psig had little effect on either the  
15 performance of the nebulizer or the resulting aerosol size distribution. Thus, the pressure was kept constant at 40 psig. Studies of the effect of flow rate on nebulizer performance and aerosol size distribution were also conducted. As the flow rate was  
20 decreased from 5 to 2 L/min, aerosol particles had progressively larger mean aerodynamic diameter. At a flow rate 8 L/min, there was excessive foaming. Thus, all studies were conducted at a flow rate of 6 L/min.

Suspension and Nanoparticle nebulization Formulations  
25 for nebulization consisted of a 0.2% beclomethasone dipropionate dispersions with PVA. The nebulizers contained either a volume of 2 mL or 6 mL. Two concentrations of PVA were used which were prepared by diluting the original 5% (w/v) nanoparticle dispersion  
30 with a PVA solution having the same PVA concentration as the original dispersion concentration or with water. The nebulizer was filled, and aliquots of the solution were taken for subsequent determination of drug concentration. The weight was also determined. The  
35 nebulization process was initiated by opening the valve

on the main gas cylinder, and the length of time until foaming or sputtering of the nebulizer was determined, and additional aliquots were taken for analysis. The fraction of mass exiting the nebulizer was calculated  
5 from the weight difference of the nebulizer before and after nebulization. This was coupled with the time required for nebulization of the dispersion to yield the mass output rate in terms of the milliliters of dispersion nebulized/unit time and the nebulizer output  
10 in terms of the volume of dispersion nebulized/liter of air were determined.

Aliquots taken from the nebulizer were diluted with 50% (v/v) ethanol in water, and the absorbance determined at 240 nm. With measurement of the  
15 absorbance of appropriate standards, the concentration of BDP was calculated. From the masses of the nebulizer before and after nebulization and the BDP concentrations, the fraction of BDP remaining in the nebulizer was calculated. The mass of BDP collected on  
20 the cascade impactor and the aerosol particle size distribution was determined by extracting the impactor stages with 10 mL of the ethanol/water solution. Aliquots were taken and the absorbances and subsequent concentration were determined. The mass median  
25 aerodynamic diameter and geometric standard deviation of the particle distribution was obtained by plotting the cumulative mass on the stages of the impactor as a function of the log of the cut-off diameter. With the cumulative mass determined from the cascade impactor  
30 and the initial amount of BDP placed in the nebulizer, the fraction of BDP reaching the impactor was calculated.

To assess the fractionation of the dispersion, the nanoparticles and suspensions were diluted with PVA  
35 solutions containing 0.1% sodium fluorescein.

Nebulization was conducted as described above. Since fluorescein has significant absorbance at both 490 and 240 nm while BDP has absorbance only at 240 nm, the absorbance of the diluted aliquots was determined at these two wavelengths. The concentration of fluorescein was determined from the absorbance at 490 nm and the measured absorptivity. In determining the concentrations of BDP, the contribution from the absorbance of fluorescein at 240 nm was subtracted based on the absorbance determined at 490 and the correction for the differences in the absorptivity at these two wavelengths.

Scanning Electron Microscopy SEM was performed on nanoparticles after nebulization. Two dispersions were prepared containing 0.1 and 2.5% surfactant. These were placed in the nebulizer and 2 cm rectangular glass microscope slides were placed on every stage of the impactor. The glass slides were removed and sputtered with platinum. Micrographs were obtained with a JEOL 840-II ElectroScan Environmental ESEM (Peabody, Mass.).

## RESULTS

Nanoparticles of beclomethasone dipropionate in 2.5% polyvinyl alcohol had a particle size distribution of  $0.26 \pm 0.13 \mu\text{m}$ . This size remained constant throughout the course of the study; neither was there any evidence of chemical instability. In addition, particle size of the diluted dispersions remained constant for at least the duration of the experiment.

For nebulization, four formulations were tested. These are listed in Table I. The first was a suspension of raw drug substance BDP in 2.5% surfactant with a volume of 2 mL. The second was composed of a dispersion of nanoparticles thereby allowing direct comparison to the suspension formulation. The third

was also a colloidal dispersion, but the surfactant concentration was smaller at 0.1%. The fourth was similar to the third but contained a larger volume of 6 mL.

5           In Table II, the results from the nebulization of the four formulations were given. The second column provides the mass output rate which was the rate at which the total mass of the dispersion exists the nebulizer. Formulations I and II are similar as were  
10 formulations III and IV. The difference between these two sets of formulations is that I and II had a surfactant concentration of 2.5%, whereas III and IV had a surfactant concentration of 0.1%.

          The third column reflects the total mass fraction  
15 of dispersion remaining in the nebulizer. The fraction of mass remaining was between 0.27 and 0.69 indicating considerable amount of material remained in the nebulizer. In addition, formulations I, II and III were similar, but formulation IV had a significantly  
20 lower mass fraction remaining in the nebulizer. Formulation IV is distinct from the others in that it contained an initial volume of 6 mL.

          In the next column, the fraction of BDP remaining in the nebulizer is given. These fractions ranged from  
25 0.29 to 0.89. In comparing the fractions remaining, formulation I, which contained the suspension, had about 90% of BDP remain in the nebulizer. In contrast, formulation III which contained 0.1% surfactant, had a significantly lower fraction of BDP remain in the  
30 nebulizer. An even more dramatic drop in fraction remaining was observed with formulation IV which had a low surfactant concentration as well as a larger volume.

It is also noteworthy to compare the fraction of BDP remaining relative to the fraction of total mass remaining in the nebulizer. With formulation I, there was a significantly greater fraction of BDP relative to the total mass remaining. Numerically this is also true for formulation II: however, there was more variability in these measurements which had no statistical difference in the fractions remaining. In formulations III and IV, there was no difference.

The fraction of BDP reaching the nebulizer is also given in Table II. It is seen that only about 7% of the BDP presented as a suspension or raw drug substance reaches the impactor. In comparison, the use of nanoparticles led to a significantly higher fraction reaching the impactor. These ranged from 0.17 to over 0.34. In formulations II and III which contained 2 mL of dispersion, about 18% of BDP reached the impactor. In the large volume formulation IV, almost 35% of BDP reached the impactor.

Finally, it is evident that the amount of BDP that was originally placed in the nebulizer should equal the amount of BDP remaining in the nebulizer added to the amount of BDP on the impactor. Expressing the mass balance in terms of fractions, the fraction of BDP remaining in the nebulizer plus the fraction of BDP on the impactor should equal unity. As can be deduced from the fractions given in Table II, this was only the case with formulation II. In other cases, there was a net loss of BDP. In particular, for formulation III, only 80% of BDP was accounted for, and in formulation IV, the percent accounted for dropped to about 60%.

It is evident when the fraction of BDP collected on the impactor stage is plotted as a function of the cut-off diameter of the stage that suspensions of raw drug substance have a distribution of particles with a

larger size and its distribution is more polydisperse. The nanoparticles have particles size distributions with 80% of the particles being less than 2.5  $\mu\text{m}$ .

5 In Table III, the results from the fluorescein study are given. In comparing the mass exited, both formulations gave similar results of about 0.75. There was also no significant difference between the fractions of BDP and fluorescein remaining in the nebulizer. For the suspension, the fraction of BDP and  
10 fluorescein remaining were 88 and 89%, respectively. For the nanoparticles, the percents were 81 and 85 which are not statistically different from each other. In addition, there was no statistical difference in the fractions of BDP and fluorescein remaining in the  
15 nebulizer between formulations I and II. However, the fractions of BDP and fluorescein remaining are significantly greater than the fraction of total mass remaining for the suspension and nanoparticle formulations.

20 The fractions of BDP reaching the impactor were different between the two formulations. For the suspension, the fraction of fluorescein collected on the impactor was almost twice as high as the fraction of BDP. For the nanoparticles, the fraction of  
25 fluorescein was similar to that found with suspensions. The fraction of BDP collected on the impactor was much higher than observed with suspensions, but slightly less than that observed with fluorescein.

30 The final study was an examination of the particles after being subjected to the process of nebulization. Scanning electron microscopy was conducted of the nanoparticles deposited on the sixth stage of the impactor for the 2.5 and 0.1% nanoparticles

Table I

Formulation Components

<u>Formulation</u>	<u>Form</u>	<u>[Surfactant]</u>	<u>Volume (mL)</u>
I	Suspension	2.5%	1.85
II	Nanoparticle Dispersion	2.5%	1.85
III	Nanoparticle Dispersion	0.1%	1.85
IV	Nanoparticle Dispersion	0.1%	5.85

Formulation "I" is a comparative formulation not using nanoparticles.

5

Table II

Comparison of Nebulization Output Parameters as a Function of Formulate Effect of Nebulization Process on Resulting Aerosol Production. Results are expressed as the mean  $\pm$  standard deviation, n=3.

Formulation	Mass output rate (mg/sec)	Mass fraction remain.	BDP fraction remain.	BDP fraction on impactor
I	2.73 $\pm$ 0.5	0.69 $\pm$ 0.036	0.89 $\pm$ 0.013	0.082 $\pm$ 0.012
II	2.61 $\pm$ 0.14	0.51 $\pm$ 0.15	0.768 $\pm$ 0.23	0.184 $\pm$ 0.47
III	4.99 $\pm$ 0.31	0.67 $\pm$ 0.006	0.618 $\pm$ 0.025	0.174 $\pm$ 0.019
IV	4.35 $\pm$ 0.65	0.27 $\pm$ 0.015	0.289 $\pm$ 0.039	0.345 $\pm$ 0.15

Table III

Comparison of the nebulization of nanoparticle dispersions and suspensions of BDP containing a solution of fluorescein.

5 Results are expressed as the mean  $\pm$  deviation, n=3.

Formulation	Mass fraction remaining	BDP fraction remaining	Fluorescein fraction remaining	BDP fraction on impactor	Fluorescein fraction on impactor
Suspension	0.76 $\pm$ 0.06	0.88 $\pm$ 0.046	0.89 $\pm$ 0.13	0.067 $\pm$ 0.02	0.122 $\pm$ 0.033
Nanoparticles	0.74 $\pm$ 0.017	0.81 $\pm$ 0.088	0.85 $\pm$ 0.065	0.11 $\pm$ 0.016	0.143 $\pm$ 0.020

#### Example 2 Using a Contrast Agent

10 In this example, a suspension of WIN 68209 (30%) in aqueous F108 surfactant (6%) was prepared by conventional roller milling techniques (jar mill, zirconium silicate beads, 7 days milling time). The mean particle size of the resultant distribution was 196 nm. The formulation was administered to an anesthetized rabbit as follows: Several mL of  
 15 formulation was placed in an ultrasonic nebulizer (DeVilbiss AeroSonic (TM)) which was connected in-line with a mechanical ventilator, terminating in a suitable endotracheal tube. The rabbit was then intubated and administered the nebulized formulation for several  
 20 minutes. Subsequent computed tomography (CT) scans of the rabbit's pulmonary region showed the presence of radiopaque contrast agent in the region.

25 The invention has been described with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

Claims:

1. An aerosol comprising droplets of an aqueous dispersion of nanoparticles, said nanoparticles  
5 comprising insoluble therapeutic or diagnostic agent particles having a surface modifier on the surface thereof.
2. An aerosol according to claim 1 wherein said  
10 diagnostic agent is benzoic acid, 3,5-bis(acetylamino)-2,4,6-triido-, 4-(ethyl-3-ethoxy-2-butenate) ester (WIN 68209).
3. A method for forming an aerosol of an aqueous  
15 dispersion of nanoparticles, said nanoparticles comprising insoluble therapeutic or diagnostic agent particles having a surface modifier on the surface thereof, said method comprising the steps of:  
a) providing a suspension of said nanoparticles;  
20 b) nebulizing said suspension so as to form an aerosol.
4. A method of treating a mammal comprising the steps of:  
a) forming an aerosol of an aqueous dispersion  
25 of nanoparticles, said nanoparticles comprising insoluble therapeutic agent particles having a surface modifier on the surface thereof;  
b) administering said aerosol to the respiratory system of said mammal.  
30
5. A method according to claim 4 wherein said aerosol is administered in a manner such that it reaches the lung.
- 35 6. A method of diagnosing a mammal, said method comprising the steps of:

- a) forming an aerosol of an aqueous dispersion of nanoparticles, said nanoparticles comprising insoluble diagnostic imaging agent particles having a surface modifier on the surface thereof;
  - 5        b) administering said aerosol to the respiratory system of said mammal; and
  - c) imaging said imaging agent in said respiratory system.
- 10        7. A method according to claim 6 wherein said diagnostic imaging agent is benzoic acid, 3,5-bis(acetylamino)-2,4,6-triiodo-, 4-(ethyl-3-ethoxy-2-butenate) ester (WIN 68209).

**AEROSOLS CONTAINING NANOPARTICLE DISPERSIONS**

**ABSTRACT OF THE DISCLOSURE**

There is disclosed an aerosol comprising droplets of an aqueous dispersion of nanoparticles, said  
5 nanoparticles comprising insoluble therapeutic or diagnostic agent particles having a surface modifier on the surface thereof. There is also disclosed a method for making the aerosol and methods for treatment and diagnosis using the aerosol.